# *Speculations Concerning the Dependence of Emission Line Contour on Frequency Shift in the Scattering of Monochromatic Radiation*

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*ABSTRACT*

The importance of small red wavelength shifts occurring in the scattering of visible light is discussed with regard to the interpretation of the contour of stellar emission lines.

The observed distribution of the intensity of stellar radiation as a function of wavelength has led to conclusions concerning the structure of the universe. In view of the importance of these conclusions, one should make certain that no possible causes contributing to the form of the contour have been ignored. Small red shifts accompanying scattering, besides those originating in the Doppler effect, have been observed and are discussed theoretically below. Thus if the conditions are such that scattering accompanied by wavelength shifts plays a role in determining the shape of this curve, then the results might be significantly altered from those obtained without considering the contribution to the curve of this particular type of scattered radiation.

Cabanne and Daure (C.R. 186, 1533, 1928) reported a red shift of the Rayleigh lines of the order of 0.06 A in a variety of liquids. This was later confirmed by Vacher (C.R. 191, 1121, 1930). I observed similar data (Phys. Rev. 34, 1061, 1929), namely a red shift in the intense scattering at small angles of light passing through a Kerr cell operated at 300 MHz with water as the dielectric. This effect may arise from the orientation of the water dipole in the field to form a coarse grating as suggested by Dodd and Sanchez (Amer. Phys. Soc. Bull., Ser. II, 13, GF5, 101, 1968). Finally, Singh (Proc. Phys. Soc. London 66A, 309, 1953) showed that Raman lines of $CCl_4$ excited by the Hg 4358 A line suffered a red shift when an electric field was impressed across the liquid. He suggested that the electric field may have induced an ordered orientation of the liquid molecules modifying the conditions under which scattering occurs. All these observations were made with liquids because the scattering in gases is of very low intensity and the measurements of the line profile tend to be obscured by stray diffused light.

These observations have been largely ignored in calculating the distribution of scattered radiation. Conditions in the stellar atmospheres are often such that multiple scattering predominates. This situation makes it all the more important

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that the analysis of the scattering process be adequate and all inclusive.

Another relevant aspect which I found (Electron. Letters 3, 266, 1967) is the scattering of ultrashort monochromatic coherent pulses, about 100 wavelengths long, by free electrons. This process occurs as a result of the rectifying interaction of ultrashort pulses with a nonlinear intensity gradient with free electrons in a highly ionized medium. Consider an asymmetric light pulse propagated in the z-direction and polarized in the y-direction. Let the envelope of the absolute value of the electric vector E be triangular in shape as expressed in Eq. (2) of my earlier paper (Electron. Letters 3, 266, 1967). Carrying out the indicated integration over the duration T of the light pulse, we obtain for the change in the momentum $M_z$ of the light pulse

$$M_z = -\frac{e\mu\bar{v}_x}{6\nu}\,\frac{H_{max}}{N^2}$$

The bar denotes the average value of the electron velocity in the x-direction during the passage of the light pulse. This change in momentum requires the energy of the light pulse to change by an amount $\Delta W = cM_z$. The parameters are shown in Table 1.

It is obvious that in the absence of a third process, the conservation of energy and momentum cannot be maintained in the interaction of a free electron and an electromagnetic pulse.

The interaction of the electron with the ionized medium may be of sufficient strength to make possible a transfer of momentum to a third particle, an ionized atom or molecule, so that the electromagnetic energy change can be assumed by the electron. The other alternative is the radiation of electromagnetic energy by the accelerated electron or, what is probably equivalent, a redistribution of the waveform for the coherent ultrashort pulse to satisfy the conservation of energy consistent with the value for the electromagnetic momentum.

For values of $E_{max} \leq 1.5\ 10^{10}$ v/m, readily obtainable in continuous coherent light beams, a wavemechanical representation is required. However, the rectifying interaction considered here is generated for the typical case $N = 100$, $\lambda = 1\cdot 10^{-6}$ m by a pulse 0.1 mm in length. In this region, the classical electromechanical approach should be valid.

The final consideration concerns the magnitude of the energy transferred between the ultrashort light pulse and the electron. This transfer will occur between a single photon and the electron.

On the basis of the parameters listed in Table 1, we obtain $\Delta\nu/\nu = 1\cdot 10^{-5}$. The agreement between this result and the experimental data cited above is purely coincidental. In stellar radiation processes, possible values of v as high as $10^8$ m/sec have been considered. The value of $E_{max} = 1.6\cdot 10^5$ v/m is in the lower range for $E_{max}$ in ultrashort pulses produced in the laboratory. It it is assumed that $\bar{v} \sim 5\cdot 10^7$ m/sec and $E_{max} \sim 3\cdot 10^6$, then $\Delta\nu/\nu$ is $1\cdot 10^{-2}$.

If collisions are to play a significant role in the rate of adjustment of momentum and energy, then the lower limit for the density of electrons and atoms or molecules in an ionized medium is $10^{13}$ per $m^3$. Since in this process the radiation from the accelerated electron is emitted at the collision with an ionized atom or molecule, the radiation pattern resulting from the interaction of an ultrashort coherent pulse with a free electron will approach that of an antenna, provided the width of the coherent light beam is much larger than $N\lambda$.

**Table 1. Terminology and Typical Values for the Parameters**

| Parameter | Symbol | Typical value |
|---|---|---|
| Velocity of light | c | $3\cdot 10^8$ m/sec |
| Magnetic field, maximum absolute value | $H_{max}$ | $0.4\cdot 10^3$ amp-turn/m |
| Average electron velocity in x-direction | $\bar{v}_x$ | $1\cdot 10^6$ m/sec |
| Frequency of light | $\nu$ | $3\cdot 10^{14}$ sec$^{-1}$ |
| Number of wavelengths per pulse | N | 100 |

The wavelength shift on scattering may well play a significant role in the interpretation of stellar observations. In the measurements by Wilson, discussed by Unsöld ("Der neue Kosmos," 195, Springer, Heidelberg, 1967), the half-width of the emission lines of stars of spectral type G to M* was found to be substantially greater than expected. The observations on the contour of the emission lines fit in with the data presented in this note. In the case of multiple scattering of a high order, the contour of an emission line is fundamentally changed. This does not represent an absorption of energy but a displacement of energy in the blue towards the red end of the spectrum.